Technische Universität Berlin

Investigating perceptual completion in a real-world experiment

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A Bachelor Thesis by:

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in **Computer Science (B. Sc.)**

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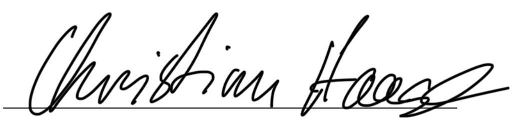

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Abstract

This study investigates the differences in perception between a digitally presented stimuli and a real-world experiment. In order to do this, a digitally presented stimuli by Scherzer and Ekroll (2015) was replicated as close as possible and presented through a 3D printed apparatus. The study by Scherzer and Ekroll (2015) showed an occluder rotating in front of a background. The occluder has an opening, which hides and reveals 12 dots. The dots are evenly distributed on a circular path. As the occluder rotated, the participants had to count the number of dots they could see. How many dots were actually visible was determined by the size of the missing sector of each occluder. Five different occluders were tested. The results show, that participants perceived more dots than were actually visible with each occluder. Not all details from the study by Scherzer and Ekroll (2015) could be replicated. Nevertheless, the results indicate that perceptual completion was experienced in a comparable way as in the virtual setting by Scherzer and Ekroll (2015).

Zusammenfassung

Diese Studie untersucht die Unterschiede in der Wahrnehmung zwischen einem digital präsentierten Stimulus und einem realen Experiment. Dazu wurde ein digital präsentierter Stimulus von Scherzer and Ekroll (2015) so genau wie möglich nachgebildet und mit einem 3D-gedruckten Apparatus präsentiert. Die Studie von Scherzer and Ekroll (2015) zeigte einen Okkluder, der sich vor einem Hintergrund drehte. Der Okkluder hat eine Öffnung, die 12 Punkte beim Rotieren um die eigene Achse auf- und wieder verdeckt. Die Punkte sind gleichmäßig auf einer Kreisbahn verteilt. Während sich der Okkluder drehte, mussten die Teilnehmer die Anzahl der Punkte zählen, die sie sehen konnten. Wie viele Punkte tatsächlich sichtbar waren, wurde durch die Größe des fehlenden Sektors jedes Okkluders bestimmt. Es wurden fünf verschiedene Okkluder getestet. Die Ergebnisse zeigen, dass die Teilnehmer bei jedem Okkluder mehr Punkte wahrnahmen, als tatsächlich sichtbar waren. Nicht alle Details aus der Studie von Scherzer and Ekroll (2015) konnten nachempfunden werden. Dennoch deuten die Ergebnisse darauf hin, dass die wahrgenommene Vervollständigung von Objekten in einer vergleichbaren Weise erlebt wurde, wie im digitalen Versuchsaufbau von Scherzer and Ekroll (2015).

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1 Introduction

The human brain receives visual information with the eyes, which convert light stimuli into neuronal signals with the help of the retina. These signals are transmitted to the brain, where they undergo complex processing and interpretation. This ability can be experienced in phenomena, where perception goes beyond the information that is actually visible. Two such phenomena are the modal and the amodal completion. These are mental processes through which an object is perceived as complete, even though it is partially occluded or not completely visible to the observer (Scherzer & Faul, 2019).

Modal completion describes how all contours of a stimuli are perceived, even though only some of them are physically present. These illusory contours lead to the perception of a surface that appears to lie on the background and obscures it. This object is also perceived as laying "above the stimuli" (Murray et al., 2004). The Kanizsa triangle (Figure 1a) shows a perceived triangle with completed edges between the three black circles. Additionally, the color within the triangle is perceived brighter than the "background" even though, they are the same color. Amodal completion describes the mental completion of an object that seems to "continue" behind a foreground object. The hidden areas of the object are unconsciously completed (Figure 1b). Additionally the amodal completion does not lead to perceived brightness enhancements within the completed area of the object. The object is often perceived as laying "below" the occluding object (Scherzer & Faul, 2019).

1.1 Previous work

Palmer et al. (2007) investigated the occlusion illusion. This illusion can be demonstrated using two identical black semicircles of the same size. One semicircle is aligned to a gray rectangle and appears to be bigger than the other semicircle. Figure 2 shows a example of the modal completion by completing the semicircle into a partially occluded, full circle.

Scherzer and Ekroll (2015) confirmed and extended this finding. They created multiple stimuli that are based on the occlusion illusion. These stimuli were

(a) Modal completion (b) Amodal completion

Figure 1: Modal and amodal completion: Figure (a) shows the modal completion and can be demonstrated with the Kanizsa triangle. This example shows a perceived triangle with completed edges between the black circles. Additionally, the color within the triangle is perceived brighter than the "background". Figure (b) shows the amodal completion of an object that "continues" behind an object in the foreground. The hidden areas of the object are unconsciously completed. Inspired by Scherzer and Faul (2019)

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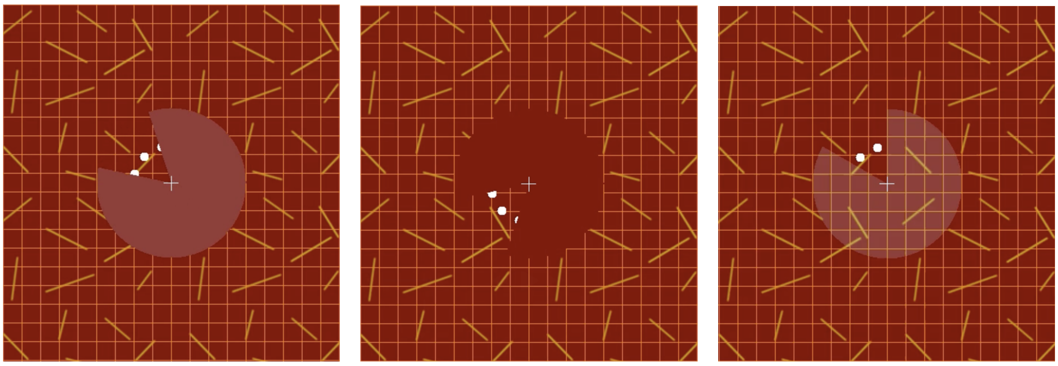
Figure 2: The Occlusion Illusion: this figure shows a partially occluded black object on the left that appears to be bigger than the non occluded black object on the right. Inspired by Palmer et al. (2007)

presented dynamically as animations on a (cathode ray tube) monitor. They conducted two experiments within their study. In the second experiment, they presented a background with evenly distributed white dots on a circumference that were partially occluded by a rotating disk with a missing sector ("occluder", Figure 3). They used three different types of occluders and two different angles of missing sectors (30 ° and 60 °). Participants had to count the white dots within the missing sector of each occluder, while the occluder was spinning.

Participants perceived an average of two dots with the 30 ° occluder, while only one to two dots were visible. The participants perceived up to four and a half dots with the 60 ° occluder, while only two to three dots were visible. Scherzer and Ekroll (2015) found that the number of perceived dots is the highest with the high-contrast occluder (Figure 3a).



(a) (b) (c)

Figure 3: Occluders and background used by Scherzer and Ekroll (2015): Figure (a) shows an occluder with high contrast. Figure (b) shows an occluder with low contrast. Figure (c) shows a semi transparent occluder, that cannot be replicated in the real-world. Source: Scherzer and Ekroll (2015)

1.2 Research question

Scherzer and Ekroll (2015) developed several stimuli based on the concept of perceptual completion. These stimuli were presented digitally on a monitor. However, it is unclear if digitally presented stimuli are perceived in the same way as comparable stimuli in real-world environments. In addition, studies with virtual settings often investigate effects that do not occur in the real world or are not physically reproducible. Most elements of the study by Scherzer and Ekroll (2015) can be replicated. However some aspects cannot be reproduced like the transparent occluder (Figure 3c) investigated by Scherzer and Ekroll (2015). This raises the following question:

How does perceptual completion under occlusion differs between digitally presented stimuli on a monitor vs. physically presented stimuli in a real-world experiment?

2 Method

An experimental method was chosen for this study, based as closely as possible on the original experiment by Scherzer and Ekroll (2015) to allow for scientific comparison.

2.1 Setup

Because not all details of the original setup were available and due to differences in scope and physical constraints, certain adjustments were necessary to obtain comparable results.

2.1.1 Apparatus

The apparatus (Figure 4) was designed to be modular in height. This grants flexibility with different headrests, portability, and fast part replacement in case of material failure. Additionally, the rapid interchangeability of the occluders was necessary to minimize the waiting time between the trials. The apparatus was designed that it could be used for other experiments with different backplates with the background design. The rotation speed and direction was adjustable. A light sensor measured the amount of light in the area in front of the apparatus. To enter numerical input, a keyboard was used. Participants then needed to validate the input through a small display in the front area of the prototype.

The step motor

A step motor is an electric motor and rotates in steps. The step motor used in this study rotated 1.8 ° per step and needed 200 steps for a 360 ° rotation. With this motor, it was possible to adjust the rotation speed and the rotation direction.

Step motor controller (SMC)

The step motor controller converted electrical signals into step signals in order to make the step motor rotate in steps. It was possible to convert one step signal into micro steps. This allowed smoother rotation and reduced vibrations that could produce distracting noises from the motor and vibrating parts.

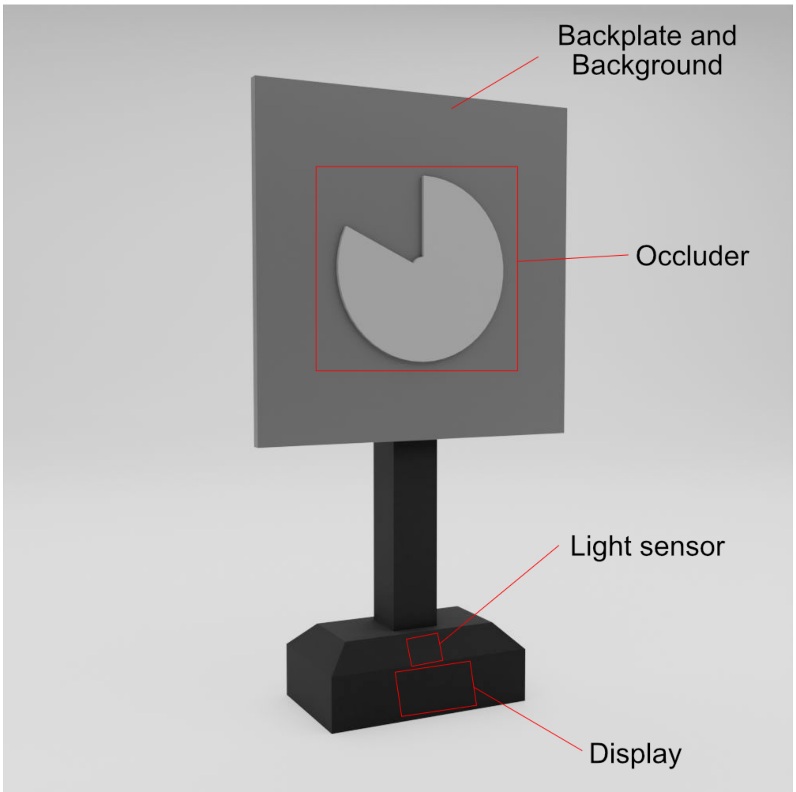


Figure 4: Apparatus Prototype Rendering.

Rotation speed and direction

In order to calculate the rotation speed, the frequency of which the SMC sends step pulses to the step motor was calculated:

$$\text{Frequency} = \text{Target rotations per second (RPS)} \times \text{Steps per full rotation} \times \text{Micro steps}$$

Scherzer and Ekroll (2015) set the rotation speed of 0.94 RPS. The step motor uses 200 steps for a 360° rotation. The amount of micro steps was set to eight.

$$\text{Frequency} = 0.94 * 200 * 8 = 1504hz$$

To reach the desired RPS of 0.94, the SMC needed to receive 1504 signals per second. The step motor was set to rotate clockwise.

The light sensor

The prototype was designed to measure the amount of light within the experimental area. This allowed the validation of the equality of the light source for each participant over the span of the experiment. If the brightness was to low, for example when no light reached the sensor, the value was discarded. This was necessary to measure the time, only when the vision block was removed from between the participant and the apparatus (see "Visual block between the participant and the apparatus" in "Experiment Setup").

The display component

The integrated display showed the participants' answer in real time. This allowed direct evaluation of their answers.

The keyboard (input device)

The keyboard allowed the participant to enter and confirm the input in order to get to the next trial.

2.1.2 Converting the stimuli

To provide portability of stimuli for use in various forms (displays, projectors, analog experiments etc.), the unit of measurement used is "visual angle" (V). This unit is widely used in the context of visual experiments (Lu & Dosher, 2013, p.63-64). The visual angle (V) can be calculated with the object size in mm (S) and the distance between the retina of the eye and the object (D, in mm):

$$V = 2\,\text{arctan}\left(\frac{S}{2D}\right) \tag{1}$$

To convert from visual angle to mm, the equation of the visual angle needs to be rearranged:

$$S = 2D \cdot \text{tan}\left(\frac{V}{2}\right)$$

Scherzer and Ekroll (2015) used visual angles most of the time (Table 1). Six of the eight sizes used by Scherzer and Ekroll (2015) were only set approximately. To ensure the reproducibility of this study, all sizes were set to a fixed value (Table 1). Using the given sizes by Scherzer and Ekroll (2015), the stimuli did not look like the original by Scherzer and Ekroll (2015). To address this problem, some

Table 1: Sizes of objects compared to Scherzer and Ekroll (2015): column "Size / Distance" was calculated and used in this project as described.
Visual Angle = V.

Object	Size / Distance	Used sizes and distances by Scherzer et al.
Stimuli distance (D)	800mm	"approximately 80cm"
Occluder	4.5 °(V)	"approximately 4.5 °(V)"
Background	9 °(V)	"about 9 °(V)"
Yellow Stripes distance	about 1.1 °(V)	"about 11 °(V)"
Dot	0.3 °(V)	"about 0.3 °(V)"
White dots circle diameter	2.5 °(V)	1.5 °(V)
Dot Distance (center to center)	30 °	30 °

sizes were adjusted to make the reproduced background look like the background by Scherzer and Ekroll (2015).

The background was the cover of the backplate and had the same size as the backplate. The background featured a dark red-brown color with an overlaying orange grid, angled yellow lines, and 12 identical white dots. Scherzer and Ekroll (2015) used a background with the size of 9 °(V) and a viewing distance of 800 mm. Using the given equation, the background had an edge length of 124.8 mm. Figure 5 demonstrates each size on a simplified background.

The white dots had a size of 0.3 °(V)(≈ 4.2mm). The dots were distributed evenly on a circumference with a 30 ° angle between the dots (center to center):

$$\text{Angle between white dots} = \frac{12}{360} = 30$$

The diameter of the white dots circular path was enlarged from 1.5 ° (V) (≈ 10.47 mm) to 2.5 °(V)(≈ 17.45 mm). Otherwise, the distance between the dots was too small and would not look like the original by Scherzer and Ekroll (2015)(Figure 6).

The described distance by Scherzer and Ekroll (2015) of the yellow lines (Table 1) was larger than the diameter of the background itself. Therefore, a fixed amount of lines per row and column was set to six lines. The lines had a random length of 10 - 20 mm, and a random rotational angle. The yellow lines were positioned

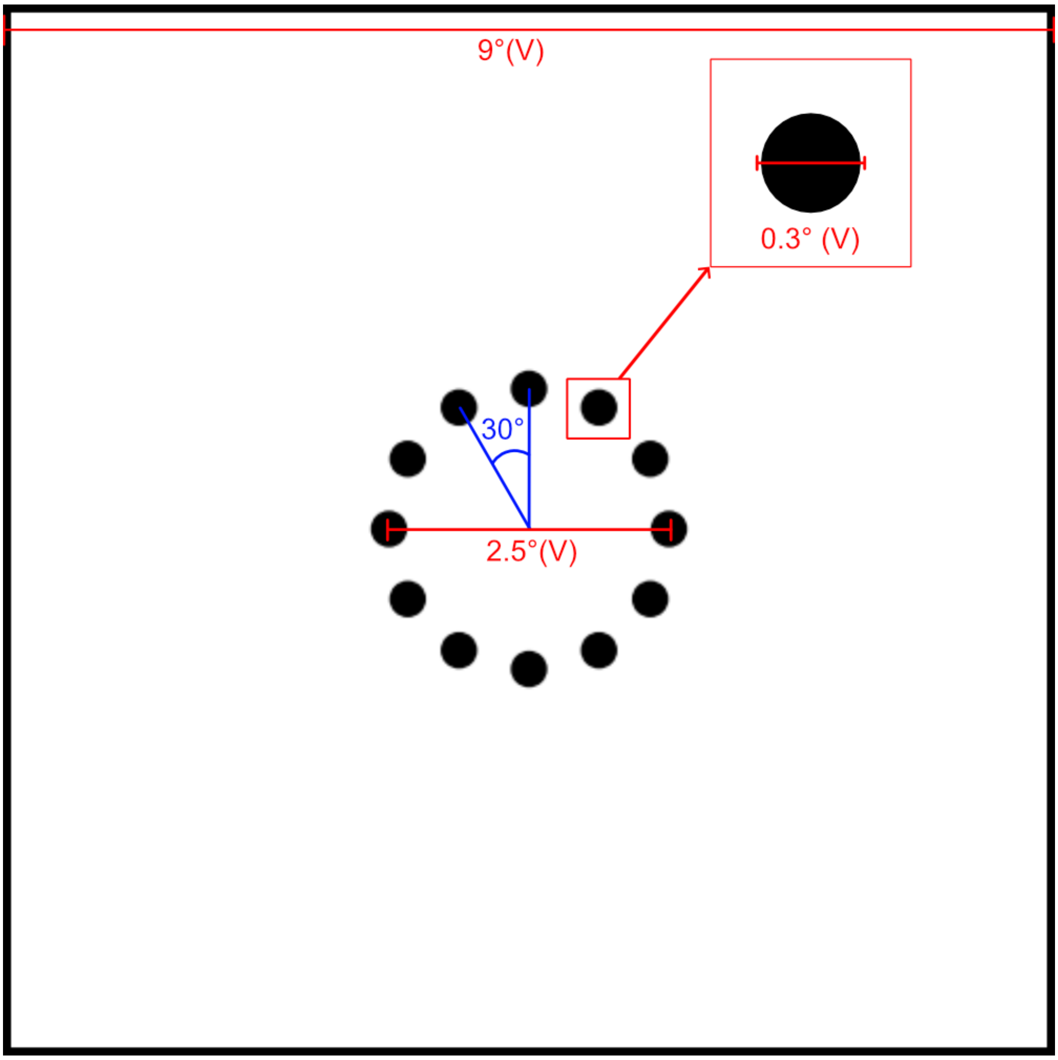
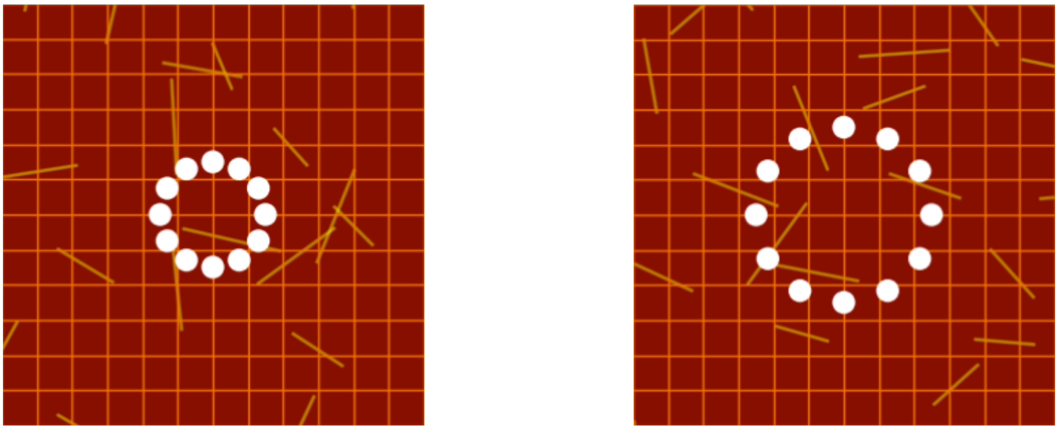


Figure 5: Background sizes example: simplified plotted background with adjusted sizes of the study by Scherzer and Ekroll (2015) (Table 1), used in this study. V = view angle. The background was placed 80 cm away from the participant. 9°V then equaled 124.8 mm.



(a) (b)

Figure 6: Comparison between the original circular path diameter and the adjusted circular path diameter: Figure (a) shows the original circular path diameter. Figure (b) shows the adjusted circular path diameter. Scherzer and Ekroll (2015) used a circle diameter of 1.5 (V)(V = view angle)(Table 1) for the white dots, which seemed to be too small, given the neat distance between two white dots (6a). In Scherzer and Ekroll (2015)'s study, a whole point apparently fitted between two dots. The adjusted circle diameter of 2.5 ° (V) for the white dots was comparable to the distance originally intended by Scherzer and Ekroll (2015).

randomly within each square of an imaginary 6x6 grid on top of the background.

Occluder

Scherzer and Ekroll (2015) used occluders with a missing sector of 30 ° and 60 °. There was no further explanation provided as to why these sizes were chosen or how they were calculated.

Own calculations showed, that the occluder of 30 ° described the angle that left a hole dot and the following space between this and the following dot (Figure 7a) open. Depending on the rotational position, more than one dot was visible. This is why the results by Scherzer and Ekroll (2015) declared, that the number of actually visible dots with the 30 ° angle of open sector was at 1.5 dots (Figure 8).

To test whether even small differences in the size of the angle of the occluders had a direct influence on the number of perceived dots, the occluders B and D (Table 2) were calculated. These occluders had a 6.9° enlarged open sector compared to occluders A and C, but showed the same number of actually visible dots as A and C (Table 2).

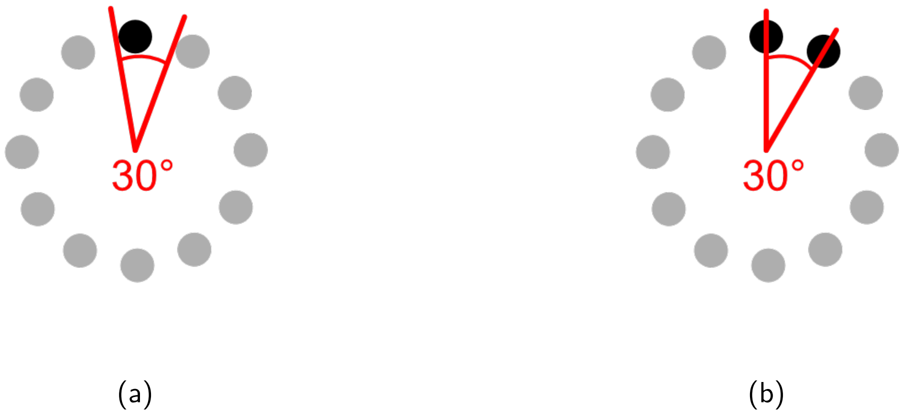


Figure 7: Influence of the occluder on the number of visible dots: Figure (a) shows the optimal position of the occluder with one dot visible. Figure (b) shows the rotated position of the occluder with two partially occluded dots. The position of the occluder defined how many dots were visible. If a dot was only partially visible, it counted as one perceived dot. For the occluder with an open sector of 30 °, one to two dots were visible.

Table 2: Variants of occluders used in this study: each occluder shows a specific number of actual visible dots in a non optimal rotation position (NOOP). If the rotational position is optimal, the "next" dot is partially visible (OOP).
Occluder A showed one dot in a non optimal rotational position (Figure 7a) and two dots, when the occluder was rotated optimally (Figure 7b). Depending on the rotational position of occluder B, which showed 1.5 dots, the same effect of seeing one to two dots was experienced. VD = exactly visible. NOOP = non optimal occluder position. OOP = optimal occluder position.

Occluder	Open Sector Angle	Visible Dots		
		VD	NOOP	OOP
A	30	1	1	2
B	36.9	1.5	1	2
C	60	2	2	3
D	66.9	2.5	2	3
E	90	3	3	4

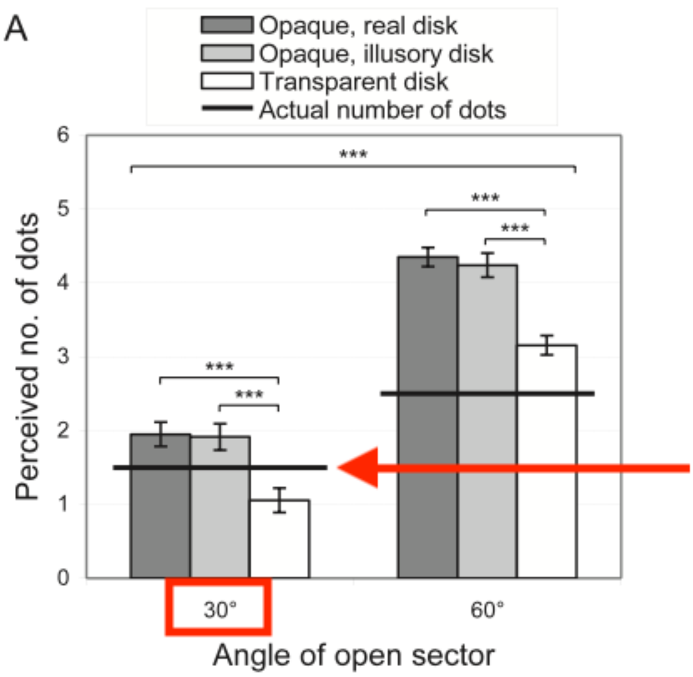


Figure 8: Number of actually visible dots: the number of actually visible dots was one to two dots, using the occluder with an open sector of 30 ° (Scherzer & Ekroll, 2015). Depending on the current rotational position of the occluder, one or two dots were (partially) visible. A partially visible dot was counted as a full dot.

2.1.3 Experiment setup

The participants conducted the experiment in the vision lab of the university. The room used window blinds to reduce the daylight. The ceiling lighting was switched off and the area of the apparatus was surrounded by black curtains who minimized the light from outside the setup. The apparatus was placed on a black table, 800 mm away from the edge of the table where the headrest was mounted to the table.

Illumination

The study environment was illuminated by a single LED spotlight (ilux LEDpro 1000LF, with the brightness level of the lamp set to 4) on a tripod at the height of 175 cm (center of lampshade). The lamp was angled down towards the apparatus. The tripod with the lamp stood approximately 50 cm away from edge of the table.

The light sensor that was integrated into the apparatus measured 193.5 lux with no person sitting within the setup. The light sensor measured the average

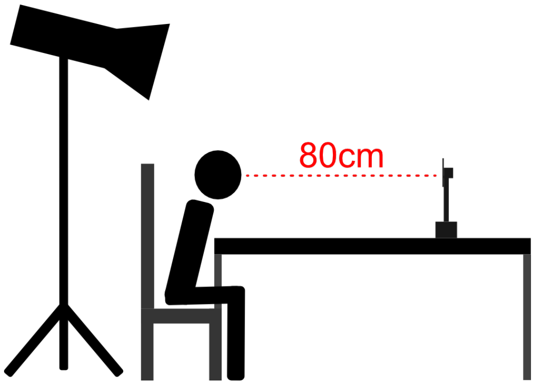


Figure 9: Experiment setup: this Figure shows the setup of this study. The apparatus was placed 80 cm away from the participant. Participants used a headrest to maintain the distance and the hight to the apparatus.

brightness of each trial (Figure 22). Thick black curtains surrounded the study setup to block light from outside.

A Konica Minolta LS-100 was used to measure the brightness within the setup, as follows: the top corners measured approximately 38 cd/m^2. The bottom corners measured approximately 32 cd/m^2. The white dots measured approximately 56 cd/m^2, the occluder measured approximately 33 cd/m^2 and the background behind the prototype (black curtains) measured approximately 2.5 cd/m^2.

Headrest

The headrest was mounted in the middle of the table and set to a fixed distance (height) of 30 cm between the chin rest and the table top. This height was fixed for each participant in order to avoid the participant casting a shadow on the apparatus. The height of the headrest matched the level with the backplate of the apparatus.

Visual block between the participant and the apparatus

The occluders were changed after each attempt. To do this, the current occluder was stopped in order to be changed. The participant sit directly in front of the apparauts and could then predict the actual number of dots. To eliminate this effect, a visual block was made of brown cardboard that was placed between the participant and the apparatus, when the respective occluder was changed.

2.2 Study design

Variables

The dependent variable was the number of perceived white dots on the background and the independent variable was the used angle of open sector of each occluder (Table 1).

Study guidelines

The study followed along the second experiment by Scherzer and Ekroll (2015). Instead of a digitally presented stimuli on a monitor (Figure 3), a physical prototype (Figure 4) presented the digital stimuli "converted" into a physical equivalent stimuli in a real-world experiment.

Occluders

Scherzer and Ekroll (2015) tested three differently colored occluders. This study focused on the high-contrast occluder (Figure 3a) that had the highest number of perceived white dots. The occluder by Scherzer and Ekroll (2015) had a white fixation cross in the center. Given the physical limitations, the occluders in this study did not use a white fixation cross in the center.

Scherzer and Ekroll (2015) used two differently sized missing sectors (30 $^{\circ}$ and 60 $^{\circ}$, Table 2, occluder A and C). Because this study focused only on the high-contrast occluder, there were five occluders with different sized angles of the missing sectors used. This reduced the possibility of memory-based answers.

Participants

A total of eleven people took part in the study, consisting of eight men and three women. The age of the participants ranged from 20 to 41 years, with an average age of 26.5 years. Seven participants used glasses for eye sight correction, while all others had normal vision. All participants wore individual clothing. Before the experiments began, each participant gave consent to use their results for this study.

2.3 Task

Before the experiment began, each participant was introduced to the topic according to a written handout (Figure 18, Figure 19). The setup and procedure were explained step by step, and participants were encouraged to ask questions after each step to ensure that they had understood everything. To illustrate how the dots should be counted, a short demonstration of the Scherzer and Ekroll (2015) reference experiment was shown on a smartphone. Participants were then asked how many dots they perceived. If their response was within a reasonable range of three to five dots, this was taken as confirmation that they had understood the counting task correctly. Participants were not informed in advance about the number of different types of occlusions they would see. They were only informed that they would see at least one occluder. This should keep the participants naive towards the experiment. All participants were informed, that there will be 15 trials.

At the beginning of each trial, the experimenter placed the occluder and removed the visual block. The participant was then asked to enter the number of perceived dots on the keyboard and confirm their answer twice by pressing the enter key. The answer could be changed at any time before the second confirmation by pressing the enter key again. After confirmation, the test was completed. For better orientation, some keys on the keyboard were color-coded. The Enter key was green and the Backspace key (to reset the answer) was red.

After each trial, a new occluder was randomly selected and applied. The same occluder was never used in the following trial.

If a participant could not decide wether he perceived one dot more or less, the possibility was given to enter an range of plus minus one dots. A partially visible dot was counted as a dot. Then the mean value was calculated and determined as the answer. The participants had no time limit to answer.

3 Results

All eleven participants conducted 15 trials each and a total of 165 trials.

Figure 10 shows the result of one participant. The x-axis shows the different types of occluders, the y-axis the number of dots perceived. Each dot represents the number of dots perceived by the participant. The blue line indicates the mean average of dots perceived for all trials from the participant. The black line indicates the number of actually visible dots as a function of the occluder. For example, a value of 1.5 in the 30° occluder means that participants could perceive either one or two dots depending on the exact position of the occluder during the rotation (Figure 7). The results show, that the average number of perceived dots (blue line) is higher than the number of actual visible dots (black line) for each occluder.

Figure 11 shows the results across all participants for each occluder. This visualization corresponds to Figure 10, except each blue dot represents the average number of perceived dots by one participant across the three trials per occluder. For each occluder, the mean value of the three trials (blue dots) per participant was calculated to determine the overall average number of all participants (blue line).

On average, all participants perceived at least the number of visible dots (Table 3), which indicates that the counting task was solved correctly. A comparison between the two occluder pairs that differed by only 6.9° (occluder A and B as well as occluder C and D (Table 2)) revealed different effects. In particular, the effect was more significant for the 36.9° occluder than for the 66.9° occluder, which is shown by the difference in the magnitude of effect (MOE). Thereby the occluder A and B had a difference of 0.439 in the MOE, while the occluder C and D had only a difference of 0.273 in the MOE (Table 7). The Friedman test was performed and showed significant results and indicated that the size of the occluder has a systematic influence on the overestimation by the participants. In addition, the one sample Mann-Whitney-U-Test showed significant results for each occluder (Table 5). This suggests that participants consistently overestimated the number of dots, regardless of the occluder size. Pairwise comparisons showed (Mann-Whitney-U-Test) that only one pair of occluders differed significantly (occluder

B and D). The smallest MOE was observed for the smallest occluder, while the largest MOE was found for the second largest occluder (66.9°) with an MOE of 1.121 (Table 7). The p-values were adjusted using the Bonferroni method.

Table 3: Average dots perceived for each occluder of all participants combined (Figure 11, blue lines).

Angle open of sector in degree	ADP
30	1.848
36.9	2.287
60	3.348
66.9	3.621
90	4.590

Study results compared to Scherzer and Ekroll (2015)

In the study by Scherzer and Ekroll (2015), two occluders of different sizes (30 ° and 60 °) were tested. To achieve a direct comparison with the results of Scherzer and Ekroll (2015), occluders with 30 ° and 60 ° open sectors as well as other sizes were tested in this study (Table 2). Since Scherzer and Ekroll (2015) did not specify the mean number of perceived dots by the participants, an estimate was made by extracting approximate values from the result diagram (Figure 8). The extracted data suggests that participants in this study perceived about 1.848 dots for the 30 ° occluder, which is about 0.052 dots less than in the original study, where about 1.9 dots were perceived. Despite the fact that there are discrepancies between the test setups, a very similar number of dots were perceived. This indicates that the perception of the two studies for the 30 ° occluder was almost identical (Figure 11, Table 4).

The results for the 60 ° occluder diverged drastically compared to the results by Scherzer and Ekroll (2015). In the reference study, participants perceived about 4.3 dots. In this study, the participants perceived 3.348 dots which is 0.952 dots less than in the reference study.

A comparison between the results for the 60 ° occluder in this study and the 90 ° occluder in the present study showed a difference of 0.290 perceived dots

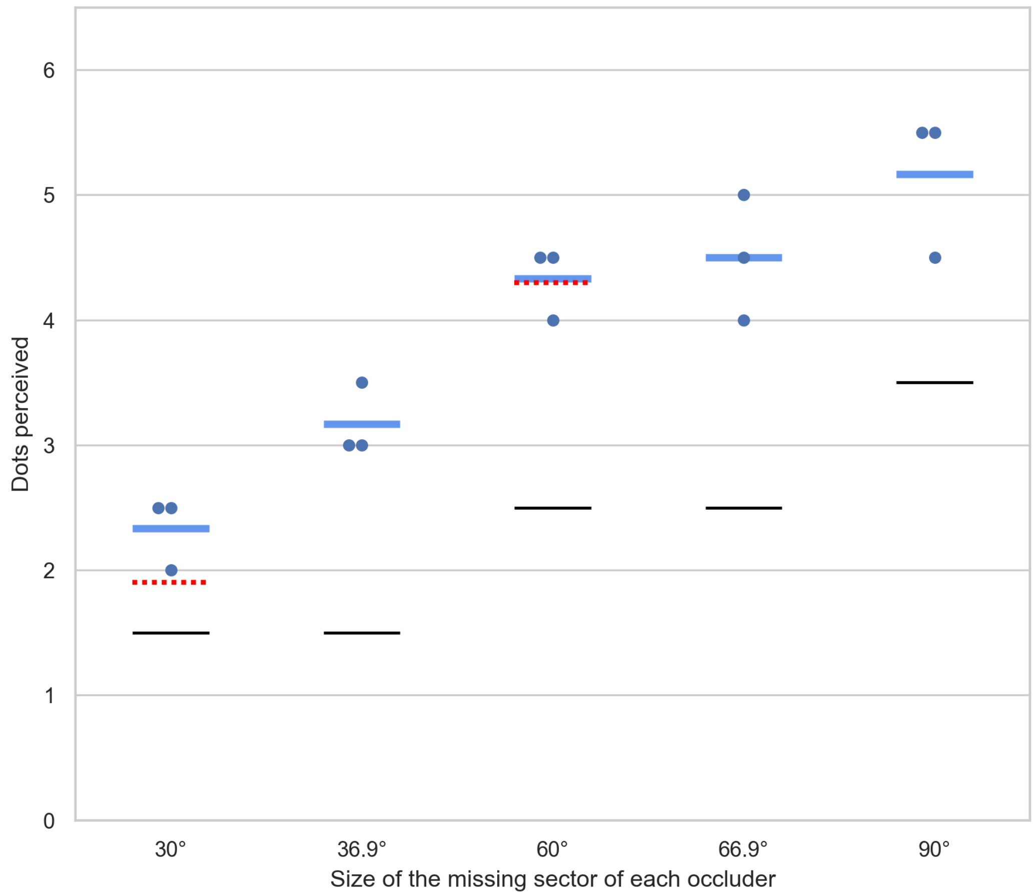


Figure 10: Results by one participant: this Figure shows the answers by one participant. The black line shows the number of dots visible. The blue line shows the average dots perceived by one participant and the red lines indicate the average dots perceived by all participants in the study by Scherzer and Ekroll (2015) for each occluder.

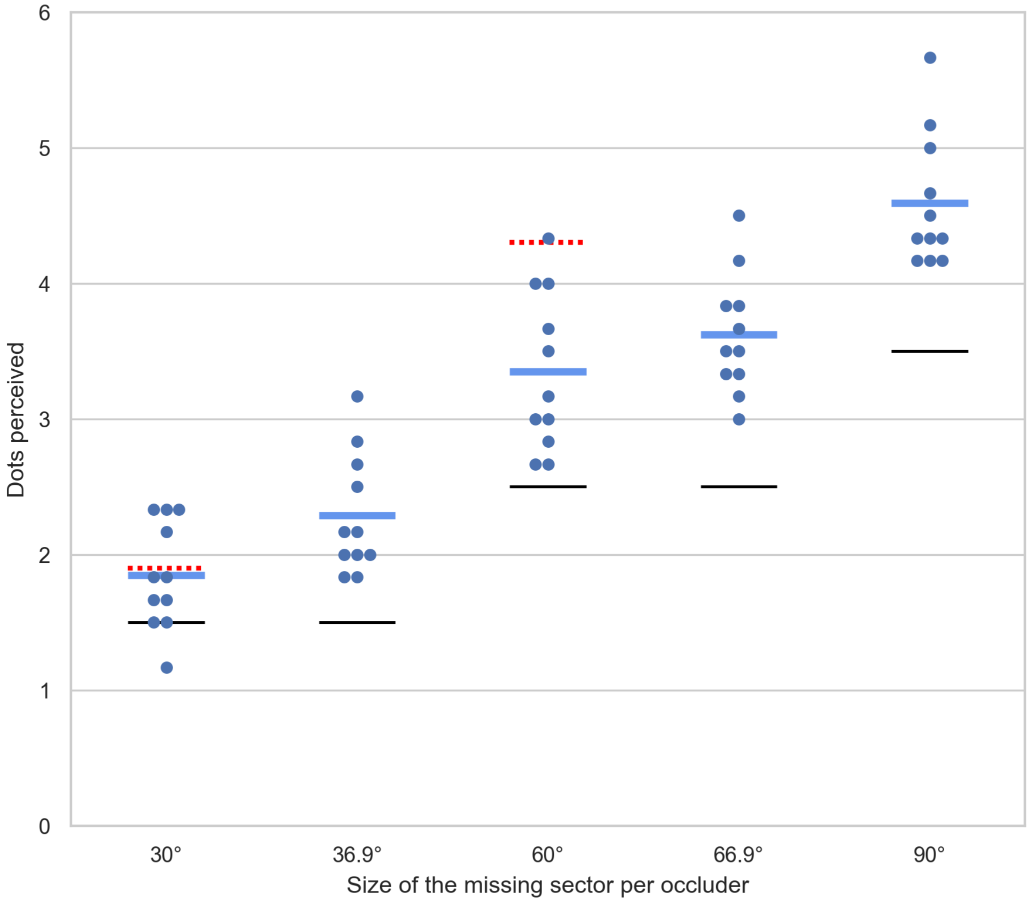


Figure 11: Average dots perceived by all participants: each dot represents the average dots perceived by one participant. The black line shows the number of visible dots. The blue line shows the overall average dots perceived by all participants. The red lines indicate the overall average dots perceived by all participants in the study by Scherzer and Ekroll (2015).

(Table 4).

The red line in Figure 10 and Figure 11 indicates the extracted results of the study by Scherzer and Ekroll (2015).

Table 4: Average dots perceived (ADP) in comparison to Scherzer and Ekroll (2015).

	Angle open of sector in degree	ADP
This study	30	1.848
Reference Study	30	1.9
This study	60	3.348
Reference Study	60	4.3
This study	90	4.590

3.1 Magnitude of effect

By comparing the results for each occluder, the relationship between the size of the open sector and the perceptual outcome can be measured.

The magnitude of effect (MOE) was calculated by subtracting the number of actual visible dots on each occluder ($30^\circ = 1.5$ dots, $60^\circ = 2.5$ dots, etc.) from the number of dots perceived by each participant per round for each occluder.

These values were then totaled and averaged by the number of observations (Table 7). The individual values are shown as blue dots in Figure 12. The blue line represents the overall average MOE for each occluder across all participants.

The MOE can be interpreted as follows: the value of the MOE for each occluder indicates how many more dots were perceived on average. The MOE was highest for the 60° at 1.121. It can therefore be said that participants perceived an average of around 1.121 additional dots (total of 4.590). It can be seen that the MOE for each occluder is greater than zero and increases with the size of the open sector of the occluder.

Due to the sample size of less than 30 participants and the use of dependent measures, a non-parametric approach was chosen for this analysis. The Friedman test was used to analyze overall statistical significance. The results indicate a significant effect ($\chi^2(4, 11) = 28.995, p < .001$). To measure the performance of each group, a one-sample Mann-Whitney-U-Test was conducted. As shown in Table 5, each group produced a significant result. The pairwise comparisons between groups were performed using the Mann-Whitney-U-Test (with the Bonferroni method)(Table 6). This analysis revealed that only one pair of occluders showed a significant difference: the 30° and the 66.9° occluder.

Table 5: One sample Mann-Whitney-U-Test for each occluder: Test the null hypothesis H_0. "Alternative" was set to "greater".

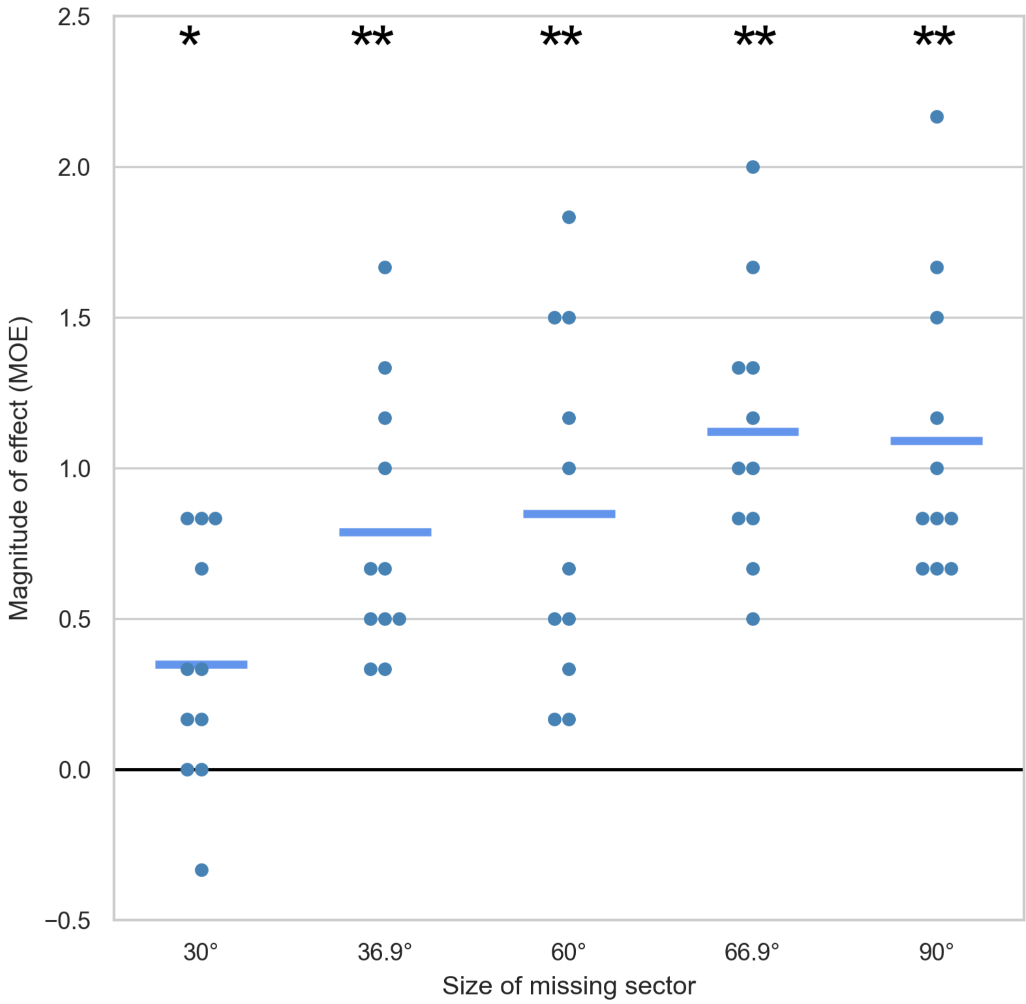
Occluder	V	n	p
30	41	11	0.0158^{*}
36.9	66	11	0.001877^{**}
60	66	11	0.001902^{**}
66.9	66	11	0.001902^{**}
90	66	11	0.001859^{**}

Note.$^{*}p < 0.05$, $^{**}p < 0.01$

Table 6: Mann-Whitney-U-Test results for each pair of occluders

Pair	Occluder 1	Occluder 2	n_1	n_2	W	p	Adjusted p-value
1	30	36.9	11	11	6.5	0.020	0.202
2	30	60	11	11	2.0	0.004	0.066
3	30	66.9	11	11	0.0	0.004	0.038^{*}
4	30	90	11	11	0.0	0.004	0.058
5	36.9	60	11	11	17.5	0.004	1.000
6	36.9	66.9	11	11	0.0	0.004	0.058
7	36.9	90	11	11	1.0	0.004	0.193
8	60	66.9	11	11	5.5	0.025	0.161
9	60	90	11	11	10.0	0.004	0.823
10	66.9	90	11	11	30.0	0.004	1.000

Note.$^{*}p < 0.05$



Note.$^{*}p < 0.05$, $^{**}p < 0.01$

Figure 12: Magnitude of effect (MOE) for each occluder: the MOE was calculated by subtracting the actual number of actual visible dots on each occluder from the number of dots perceived by each participant per round for each occluder. These values were then totaled and averaged by the number of observations (Table 7). The individual values are shown as blue dots. The blue line represents the overall average MOE for each occluder across all participants. Only one pair of occluders showed a significant difference: the 30° and the 66.9° occluder.

Table 7: Magnitude of effect (MOE) for each open sector angle (Figure 12).

Angle open of sector in degree	MOE
30	0.348
36.9	0.787
60	0.848
66.9	1.121
90	1.090

4 Discussion

The human brain processes visual input and interprets a wide range of sensory stimuli, including both modal and amodal completions. A clear example of this is a sunset: even if the sun is partially occluded by the horizon, it is still perceived as a complete, circular shape. The ability to "fill in" missing parts of the visual information shows how the brain goes beyond the raw sensory data and presents an interpretation of the world.

Scherzer and Ekroll (2015) conducted a study on this phenomenon and investigated how the brain perceives partially occluded dots and found that participants perceived more dots than were actually visible.

This study investigated whether the perception of the stimuli by Scherzer and Ekroll (2015) was the same in a real-world experiment and if it differed from their digital presented stimuli. To convert their digitally stimuli into a real-world design, an apparatus was created using 3D printing. The 3D printed apparatus is capable of rotating an occluding disk to either occlude or show some of the twelve evenly distributed dots on a circular path. The amount of actually visible dots depends on the size of the missing sector of each occluder (Table 2). Behind the occluder, the dots are displayed on a plate in accordance to Scherzer and Ekroll (2015). All participants had to count the dots they perceived while the occluder was rotating. When the participant entered a number and confirmed the answer, the experimenter then placed a visual block between the participant and the apparatus. After the occluder was changed and the next trial started, the experimenter removed the visual block by hand. Eleven participants took part in the study and completed 15 trials each.

The results show, that participants perceived more dots than were actually visible. This effect happened with each occluder. To test the significance of the results, the Friedman was performed. Because the Friedman test showed a significant result, the one sample Mann-Whitney-U was performed as well. This test was used to evaluate the significance of the results of the individual occluders, all of which were found to be significant (Table 5). The amount of perceived dots in this study does not match the results by Scherzer and Ekroll (2015) entirely. Some occluders showed a very similar amount of perceived dots like the 30°

occluder in both studies. On the other hand, the results of the 90° occluder in this study showed a similar number of perceived dots as the 60° occluder in the study by Scherzer and Ekroll (2015) (Table 4).

Therefore it can be said that there was an effect of experienced perceptual completion in the real-world experiment which is comparable but not identical to the results by Scherzer and Ekroll (2015).

4.1 Limitations

Cognitive tactics by participants

The participants were instructed to the experiment and explicitly told to focus on the center of the occluder. Nevertheless, some participants stated that they "aimed their eye at a point to count the dots" (Figure 13). It is not clear how many participants behaved this way or developed other behaviors that might influenced the number of dots they perceived.

Some participants also asked whether their answers would be compared with the results of other participants. This was denied. It is unclear whether participants still felt competitive with other participants and gave higher numbers in response.

Missing fixation spot in the center of the occluder

In the study by Scherzer and Ekroll (2015), a plus sign was used as a fixation spot in the center of each occluder (Figure 14). This fixation spot can be described as a plus sign. Since they used monitors in their studies, it was possible to prevent the fixation spot from rotating.

In this study, this fixation spot could not be replicated in the center of the occluder, because shapes that are rotated can be interpreted as a dot. This could lead to misinterpretation by the participants. The participants were told explicitly to fixate the center of the occluder, although there was no fixation spot in the center. It is not clear, how this influenced the answers by the participants.

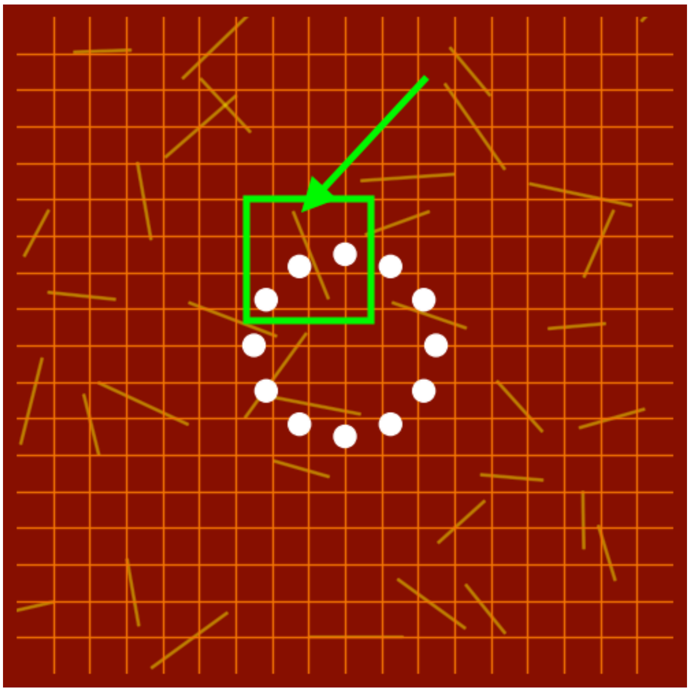


Figure 13: The visual background behind the occluder: participants used the yellow line as a "starting point" to count the dots, although they were explicitly told to look into the center of the occluder.

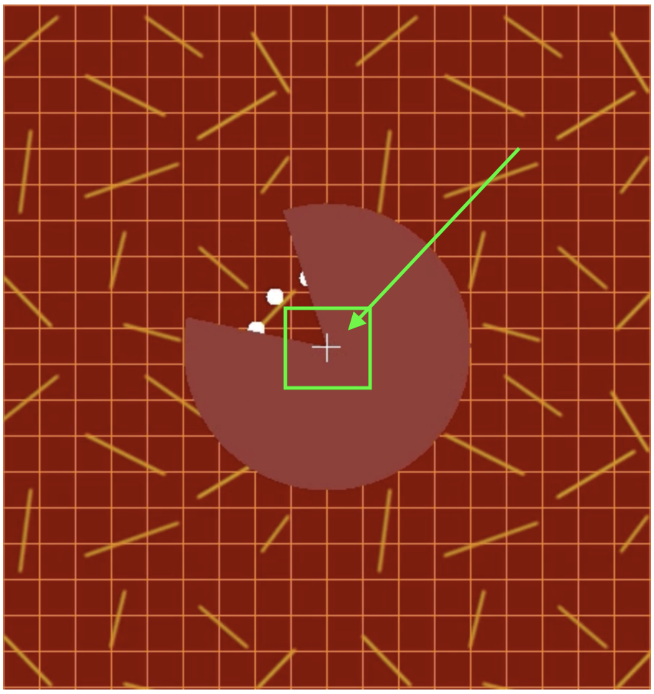


Figure 14: Occluder center fixation spot: the original study by Scherzer and Ekroll (2015) used occluders with a white fixation spot (cross) in the center of the occluder. This cross was not spinning in the study by Scherzer and Ekroll (2015). This study could not replicate this fixation spot because a spinning open, even though it is not round, could be interpreted as a dot.

Study environment by Scherzer and Ekroll (2015)

Scherzer and Ekroll (2015) did not provide detailed information of their study setup, so various methodological aspects can only be speculated upon. While it can be assumed that standard experimental procedure was followed, the lack of specific information leads to a number of potential interfering factors that may have influenced the results of this study.

One such factor is the use of an 80 Hz CRT monitor in the reference study. The brightness and contrast settings of monitors can significantly affect visual perception. A critical question remains unanswered: How bright were the white dots in their study? In addition, the visual context surrounding the monitor, such as the lighting in the room or the luminance of surfaces behind or around the screen, may have further influenced the way participants perceived the stimuli.

Without accurate documentation of these parameters, an exact replication of the study is not possible. This lack of transparency affects the reliability and generalization of the results.

Colors

The study by Scherzer and Ekroll (2015) used different colors in their study to produce the stimuli. White color was used for the dots, a red-brown for the background, orange for the underlying grid, yellow for the angled lines and a lighter red for the contrast occluder. The colors were extracted from the screenshot with a browser plugin called "color picker". To extract colors from the screenshot using the tool, a pixel from the desired element must be selected. Because the available screenshot of the reference study was in low resolution, the pixels of the elements of the background "shifted" into each other (Figure 15). This effect causes imprecise color determination. It is unclear whether every color in this study matches the same color as in the original study by Scherzer and Ekroll (2015).

Because this study took place in a real-world environment, the background with the stimuli was printed on photo paper. The used printer was an ink printer. The printed colors did not exactly match the color of the digital copy that was created in order to print the background. It was decided that the background would still be used, as the perception of the colors changed again when the spotlight was illuminating in the study setup (Figure 9). Because the ink printer printed the yellow lines on a red-brown background, the yellow lines are not as noticeable as in the digital version. The yellow lines and the orange grid appeared semi-transparent on the printed version.

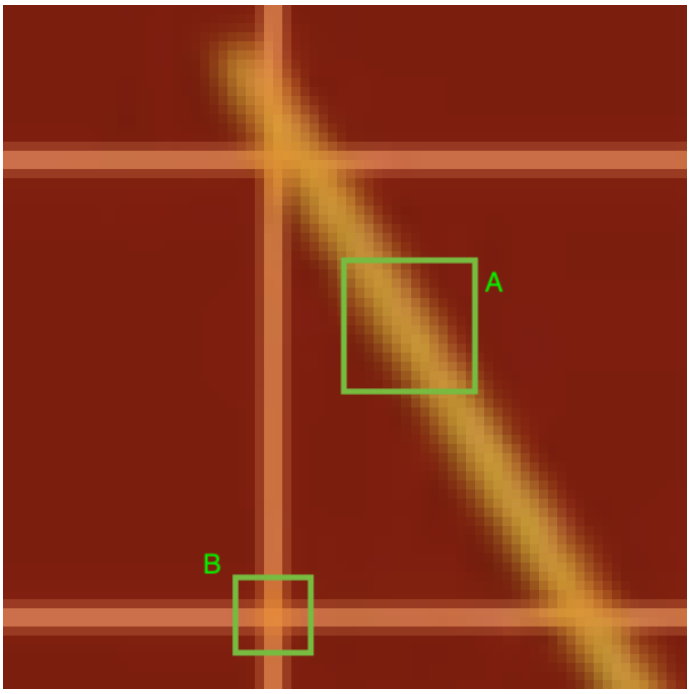


Figure 15: Color extraction of stimuli colors: it is unclear if the extracted color is the exact color used by Scherzer and Ekroll (2015). Square "A" shows a yellow line on the background. There is no indicator, which yellow tone is the correct one. Square "B" shows multiple overlaying colors of the grid on the background which appear to be semi transparent as well.

Printing of the apparatus

The experimental apparatus used in this study was produced using an additive manufacturing technique. In addition, a Creality Ender-3 (V2) 3D printer was used for printing. The printing process took place in an environment with variable ambient temperatures and fluctuating air flows. As is common with fused deposition modeling (FDM), slight dimensional deviations due to printing tolerances are unavoidable. These manufacturing deviations can influence the visual perception of the printed components and should be taken into account when interpreting the study results. The considered range of manufacturing deviations is up to $\approx 1\,\text{mm}$, especially in sharp, unrounded corners.

Visual block between participants and the apparatus

It is unclear how Scherzer and Ekroll (2015) presented the stimulus to their participants on the monitor. There are multiple options to start each trial, such as a fade in of the stimuli with an rotating occluder or a hard cut from a black screen into the rotating animation.

Because of physical limitations, the stimuli in this study was hidden from the participant when the occluder was not spinning. This was the chosen method to keep the naivety of the participants towards the experiment. Otherwise the participant could have counted the dots while the occluder was not spinning. The experimenter started the next trial after changing the occluder and before removing the visual block afterwards. Therefore the consistency of placing and removing the vision block was inconsistent and may affected the perception of the participant.

Light sensor settings and position

The apparatus was equipped with an integrated light sensor that recorded the ambient brightness for each trial individually. The sensor was located in the upper front housing of the apparatus and was aligned upwards. Due to this placement, the sensor could not detect the full range of ambient light around the apparatus. The light sensor mainly measured the visual field in front of the apparatus.

The light measurements started with the start of each trial. However, prior to removing the visual block, the ambient illumination was insufficient to obtain valid measurements with the set light sensor sensitivity settings, which resulted in an error if the visual block was placed. Once the sensor was exposed directly to the spotlight, valid measurements were recorded. All sensor data recorded prior to this exposure were systematically excluded from the calculation of the average light intensity per trial.

4.2 Open Questions

Order effect

Scherzer and Ekroll (2015) used two occluders with different sized missing sectors in their study. Because of this, it is unclear of how the order of the trials affected their results. To address this concern, this study used five different occluders which were presented in a random order with an occluder change after each trial. Each participant saw the occluders in a different order.

However, the influence of more systematic presentation sequences, such as increasing or decreasing sizes of the missing sector, or a specific perceptual pattern, remains in an open question: how do ordered stimulus sequences affect perceptual responses compared to randomized presentations?

Rotation speed and rotation direction of the occluder

Another question that arose early in the course of this study was related to the influence of speed and direction of the rotation of the occluders on the participants' perception. Scherzer and Ekroll (2015) did not explain why a rotation speed of 0.94 rpm and a clockwise direction was chosen. The question is: How can different rotation dynamics affect perceptual outcomes?

Influence of the diameter of the white dots

Scherzer and Ekroll (2015) used the visual angle in degrees unit to describe the sizes of the different elements in their stimuli (Table 1). To recreate the stimuli, the sizes needed to be converted in relation to the participant's viewing distance of 80 cm. Because Scherzer and Ekroll (2015) did not clarify the equation used to convert the sizes, a generally applicable equation was used (Equation 1). In comparison, the converted size for the white dots in this study appeared bigger than in the study by Scherzer and Ekroll (2015). To encounter this problem, the diameter of the circular path of the white dots was enlarged. It was not also not clarified. Thus, it remains open: how does the size of the dots influence the number of counted dots?

Conclusion

This study investigated, how perceptual completion under occlusion differs between digitally presented stimuli on a monitor vs. physically presented stimuli in a real-world experiment. The stimuli used by Scherzer and Ekroll (2015) was replicated as close as possible and presented with a 3D printed apparatus. As in the study by Scherzer and Ekroll (2015), people in this study perceived more dots than were actually visible. Thus, the real-world experiment and the digital experiment are comparable.

Appendices

The study data and instructions for building the prototype used in this study will be published after this Thesis work has been graded and will then be available here:
https://gitlab.com/Chrille_/ba-thesis.git

A Trial data

Table 8: Study data of all participants

Person Label	Trial	Occluder	Lux	Dots Perceived	Actual Dots	MOE
P1	1	30.0	148.6	2.5	1.5	1.0
P1	2	90.0	147.3	4.0	3.5	0.5
P1	3	30.0	147.7	2.5	1.5	1.0
P1	4	36.9	153.2	3.0	1.5	1.5
P1	5	66.9	148.5	4.0	2.5	1.5
P1	6	30.0	149.6	2.0	1.5	0.5
P1	7	60.0	152.0	4.0	2.5	1.5
P1	8	36.9	154.8	3.0	1.5	1.5
P1	9	66.9	149.7	4.0	2.5	1.5
P1	10	90.0	151.0	5.0	3.5	1.5
P1	11	36.9	150.5	2.5	1.5	1.0
P1	12	66.9	148.8	3.5	2.5	1.0
P1	13	60.0	150.8	3.0	2.5	0.5
P1	14	90.0	155.9	5.0	3.5	1.5
P1	15	60.0	155.8	3.5	2.5	1.0
P2	1	66.9	186.5	3.5	2.5	1.0

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Table 8: Study data of all participants (continued)

Person Label	Trial	Occluder	Lux	Dots Perceived	Actual Dots	MOE
P2	2	30.0	186.4	2.5	1.5	1.0
P2	3	66.9	186.4	3.5	2.5	1.0
P2	4	30.0	185.4	1.5	1.5	0.0
P2	5	90.0	186.1	4.5	3.5	1.0
P2	6	36.9	185.9	2.5	1.5	1.0
P2	7	30.0	186.1	2.5	1.5	1.0
P2	8	66.9	185.6	4.5	2.5	2.0
P2	9	90.0	184.7	5.5	3.5	2.0
P2	10	60.0	185.2	3.5	2.5	1.0
P2	11	36.9	184.5	2.5	1.5	1.0
P2	12	60.0	185.9	4.0	2.5	1.5
P2	13	90.0	184.6	5.0	3.5	1.5
P2	14	36.9	186.9	2.5	1.5	1.0
P2	15	60.0	186.1	3.5	2.5	1.0
P3	1	60.0	192.9	3.0	2.5	0.5
P3	2	90.0	187.7	4.5	3.5	1.0
P3	3	36.9	183.7	1.5	1.5	0.0
P3	4	90.0	184.5	4.0	3.5	0.5
P3	5	66.9	186.0	3.0	2.5	0.5
P3	6	60.0	185.5	2.5	2.5	0.0
P3	7	66.9	185.7	3.0	2.5	0.5
P3	8	60.0	182.8	2.5	2.5	0.0
P3	9	66.9	184.8	3.0	2.5	0.5

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Table 8: Study data of all participants (continued)

Person Label	Trial	Occluder	Lux	Dots Perceived	Actual Dots	MOE
P3	10	30.0	186.5	1.0	1.5	-0.5
P3	11	36.9	185.3	2.0	1.5	0.5
P3	12	30.0	185.7	1.0	1.5	-0.5
P3	13	90.0	185.4	4.5	3.5	1.0
P3	14	30.0	185.2	1.5	1.5	0.0
P3	15	36.9	185.9	2.0	1.5	0.5
P4	1	90.0	185.9	4.0	3.5	0.5
P4	2	60.0	186.4	3.0	2.5	0.5
P4	3	36.9	187.2	2.0	1.5	0.5
P4	4	30.0	187.6	1.5	1.5	0.0
P4	5	66.9	187.0	3.5	2.5	1.0
P4	6	90.0	186.7	4.5	3.5	1.0
P4	7	66.9	187.0	3.0	2.5	0.5
P4	8	90.0	187.3	4.0	3.5	0.5
P4	9	36.9	187.0	2.0	1.5	0.5
P4	10	30.0	186.3	1.5	1.5	0.0
P4	11	36.9	187.3	2.0	1.5	0.5
P4	12	60.0	183.8	3.0	2.5	0.5
P4	13	30.0	187.2	1.5	1.5	0.0
P4	14	60.0	185.7	3.0	2.5	0.5
P4	15	66.9	187.0	3.5	2.5	1.0
P5	1	30.0	167.2	2.5	1.5	1.0
P5	2	60.0	169.2	4.5	2.5	2.0

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Table 8: Study data of all participants (continued)

Person Label	Trial	Occluder	Lux	Dots Perceived	Actual Dots	MOE
P5	3	66.9	168.9	5.0	2.5	2.5
P5	4	90.0	167.0	5.5	3.5	2.0
P5	5	36.9	167.8	3.0	1.5	1.5
P5	6	30.0	167.8	2.5	1.5	1.0
P5	7	36.9	166.3	3.5	1.5	2.0
P5	8	90.0	166.2	5.5	3.5	2.0
P5	9	36.9	166.4	3.0	1.5	1.5
P5	10	60.0	164.9	4.5	2.5	2.0
P5	11	66.9	164.2	4.0	2.5	1.5
P5	12	30.0	164.3	2.0	1.5	0.5
P5	13	90.0	166.0	4.5	3.5	1.0
P5	14	66.9	167.1	4.5	2.5	2.0
P5	15	60.0	166.6	4.0	2.5	1.5
P6	1	30.0	149.3	2.0	1.5	0.5
P6	2	66.9	150.2	4.0	2.5	1.5
P6	3	36.9	150.6	2.0	1.5	0.5
P6	4	90.0	149.5	4.0	3.5	0.5
P6	5	30.0	148.7	1.5	1.5	0.0
P6	6	90.0	149.6	4.0	3.5	0.5
P6	7	30.0	152.6	2.0	1.5	0.5
P6	8	36.9	150.3	2.0	1.5	0.5
P6	9	60.0	150.9	3.0	2.5	0.5
P6	10	36.9	150.7	2.5	1.5	1.0

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Table 8: Study data of all participants (continued)

Person Label	Trial	Occluder	Lux	Dots Perceived	Actual Dots	MOE
P6	11	66.9	150.9	3.5	2.5	1.0
P6	12	90.0	149.9	4.5	3.5	1.0
P6	13	60.0	147.7	3.0	2.5	0.5
P6	14	66.9	149.1	3.0	2.5	0.5
P6	15	60.0	149.6	2.0	2.5	-0.5
P7	1	30.0	147.8	2.0	1.5	0.5
P7	2	66.9	148.9	3.5	2.5	1.0
P7	3	90.0	149.5	5.0	3.5	1.5
P7	4	30.0	150.6	1.0	1.5	-0.5
P7	5	60.0	150.7	2.5	2.5	0.0
P7	6	66.9	150.4	3.0	2.5	0.5
P7	7	36.9	150.6	2.0	1.5	0.5
P7	8	60.0	150.4	3.0	2.5	0.5
P7	9	90.0	149.9	4.0	3.5	0.5
P7	10	66.9	147.7	3.0	2.5	0.5
P7	11	30.0	148.4	1.5	1.5	0.0
P7	12	36.9	149.4	2.0	1.5	0.5
P7	13	90.0	150.1	4.0	3.5	0.5
P7	14	36.9	148.0	2.0	1.5	0.5
P7	15	60.0	147.0	3.0	2.5	0.5
P8	1	90.0	182.2	3.5	3.5	0.0
P8	2	30.0	184.3	3.0	1.5	1.5
P8	3	60.0	185.1	4.0	2.5	1.5

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Table 8: Study data of all participants (continued)

Person Label	Trial	Occluder	Lux	Dots Perceived	Actual Dots	MOE
P8	4	30.0	186.5	2.5	1.5	1.0
P8	5	66.9	186.2	4.5	2.5	2.0
P8	6	60.0	185.7	5.0	2.5	2.5
P8	7	66.9	185.7	3.0	2.5	0.5
P8	8	60.0	185.8	3.0	2.5	0.5
P8	9	30.0	186.4	1.5	1.5	0.0
P8	10	90.0	183.7	5.0	3.5	1.5
P8	11	36.9	184.5	2.0	1.5	0.5
P8	12	90.0	184.7	4.5	3.5	1.0
P8	13	36.9	186.2	1.5	1.5	0.0
P8	14	66.9	186.0	3.5	2.5	1.0
P8	15	36.9	174.2	2.0	1.5	0.5
P9	1	36.9	186.3	2.5	1.5	1.0
P9	2	60.0	186.2	3.5	2.5	1.0
P9	3	30.0	187.0	1.5	1.5	0.0
P9	4	36.9	186.3	2.0	1.5	0.5
P9	5	66.9	186.5	3.5	2.5	1.0
P9	6	36.9	187.1	2.0	1.5	0.5
P9	7	60.0	186.1	3.0	2.5	0.5
P9	8	90.0	187.5	4.5	3.5	1.0
P9	9	30.0	183.7	2.0	1.5	0.5
P9	10	66.9	185.4	3.0	2.5	0.5
P9	11	90.0	185.9	4.0	3.5	0.5

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Table 8: Study data of all participants (continued)

Person Label	Trial	Occluder	Lux	Dots Perceived	Actual Dots	MOE
P9	12	66.9	186.2	3.5	2.5	1.0
P9	13	90.0	185.9	4.0	3.5	0.5
P9	14	60.0	185.9	3.0	2.5	0.5
P9	15	30.0	186.0	1.5	1.5	0.0
P10	1	90.0	185.1	5.0	3.5	1.5
P10	2	60.0	183.8	4.0	2.5	1.5
P10	3	90.0	182.3	6.0	3.5	2.5
P10	4	36.9	182.9	3.0	1.5	1.5
P10	5	90.0	182.9	6.0	3.5	2.5
P10	6	60.0	181.5	4.0	2.5	1.5
P10	7	36.9	182.9	3.0	1.5	1.5
P10	8	60.0	182.6	4.0	2.5	1.5
P10	9	36.9	182.2	2.0	1.5	0.5
P10	10	30.0	182.1	1.5	1.5	0.0
P10	11	66.9	183.4	3.5	2.5	1.0
P10	12	30.0	174.2	1.5	1.5	0.0
P10	13	66.9	180.3	5.0	2.5	2.5
P10	14	30.0	181.1	2.0	1.5	0.5
P10	15	66.9	180.8	4.0	2.5	1.5
P11	1	66.9	185.7	3.5	2.5	1.0
P11	7	66.9	186.4	4.0	2.5	1.5
P11	13	90.0	186.6	4.0	3.5	0.5
P11	15	36.9	186.6	2.0	1.5	0.5

continues on next page

Table 8: Study data of all participants (continued)

Person Label	Trial	Occluder	Lux	Dots Perceived	Actual Dots	MOE
P11	8	36.9	186.8	2.0	1.5	0.5
P11	2	30.0	187.0	2.0	1.5	0.5
P11	10	36.9	187.0	2.0	1.5	0.5
P11	11	90.0	187.0	4.5	3.5	1.0
P11	12	60.0	187.0	3.0	2.5	0.5
P11	9	30.0	187.1	2.0	1.5	0.5
P11	3	90.0	187.2	5.0	3.5	1.5
P11	6	60.0	187.2	3.0	2.5	0.5
P11	5	30.0	187.5	1.5	1.5	0.0
P11	14	60.0	187.5	3.0	2.5	0.5
P11	4	66.9	187.8	3.0	2.5	0.5

Table 9: Mean dots perceived per participant.

Person Label	Occluder				
	30.0	36.9	60.0	66.9	90.0
P1	2.333	2.833	3.5	3.833	4.667
P2	2.167	2.500	3.667	3.833	5.000
P3	1.167	1.833	2.667	3.000	4.333
P4	1.500	2.000	3.000	3.333	4.167
P5	2.333	3.167	4.333	4.500	5.167
P6	1.833	2.167	2.667	3.500	4.167
P7	1.500	2.000	2.833	3.167	4.333
P8	2.333	1.833	4.000	3.667	4.333
P9	1.667	2.167	3.167	3.333	4.167
P10	1.667	2.667	4.000	4.167	5.667
P11	1.833	2.000	3.000	3.500	4.500

Table 10: Mean magnitude of effect (MOE) for each participant per occluder.

Person Label	Occluder				
	30.0	36.9	60.0	66.9	90.0
P1	0.833	1.333	1.000	1.333	1.166
P2	0.666	1.000	1.166	1.333	1.500
P3	-0.333	0.333	0.166	0.500	0.833
P4	0.000	0.500	0.500	0.833	0.666
P5	0.833	1.666	1.833	2.000	1.666
P6	0.333	0.666	0.166	1.000	0.666
P7	0.000	0.500	0.333	0.666	0.833
P8	0.833	0.333	1.500	1.166	0.833
P9	0.166	0.666	0.666	0.833	0.666
P10	0.166	1.166	1.500	1.666	2.166
P11	0.333	0.500	0.500	1.000	1.000

Table 11: Colors used for the background.

Object	Color
Grid	#f57603
Background	#870F00
Occluder	#8e413b
Yellow lines	color='yellow'
Dots	color='white'

B Plotted results for each participant

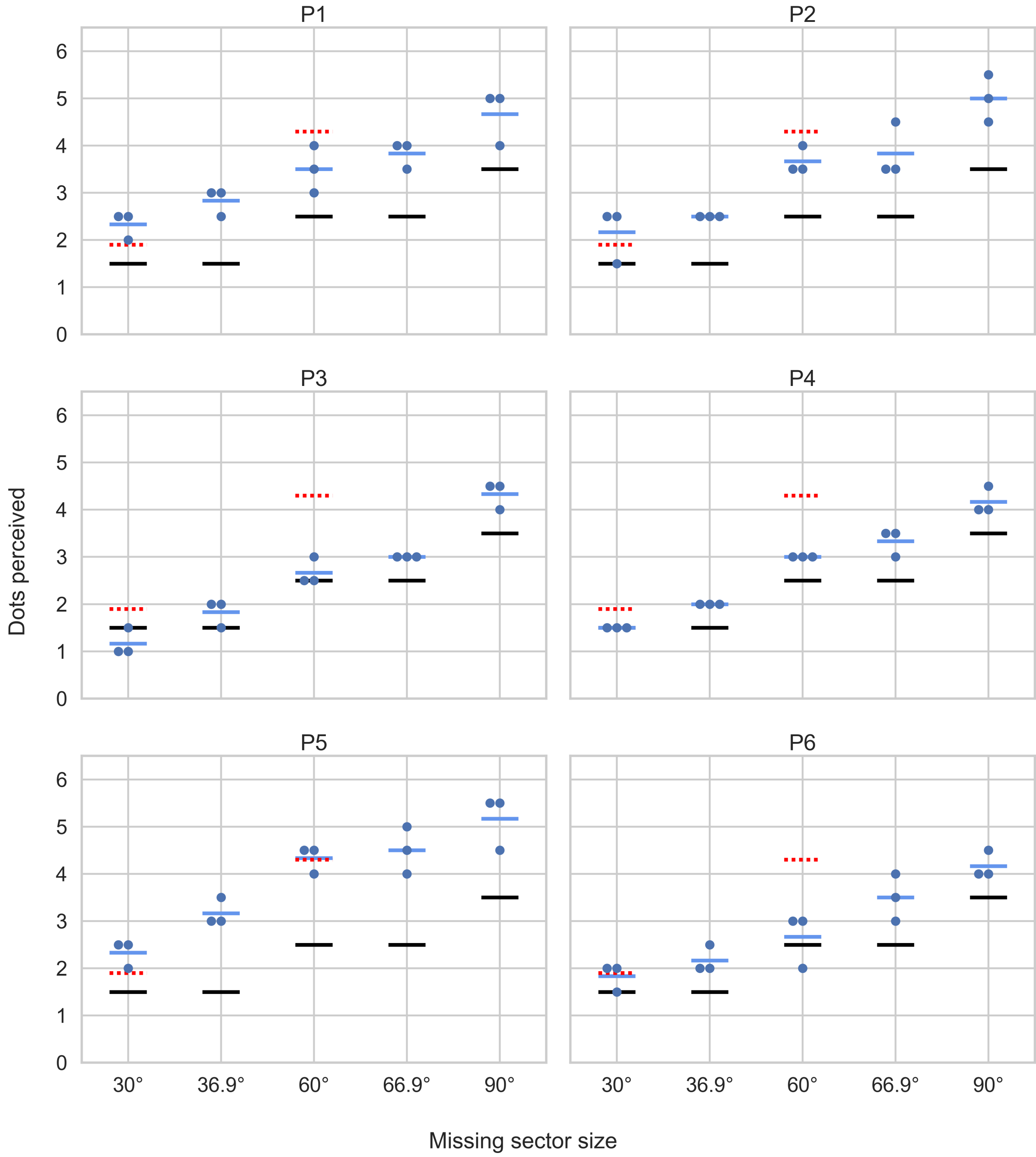


Figure 16: Participants 1-6 answer plots: the plots represent the answers given by each participant (P). The x-axis represents the size of the missing sector of the occluder. The y-axis shows the number of perceived dots by the participants. Each blue dot represents one answer by a participant for one trial. The black line indicates the amount of actual visible dots. The blue line shows the average of perceived dots by the participant. The red line indicates the results by Scherzer and Ekroll (2015) for the occluders with the 30° and the 60° occluder.

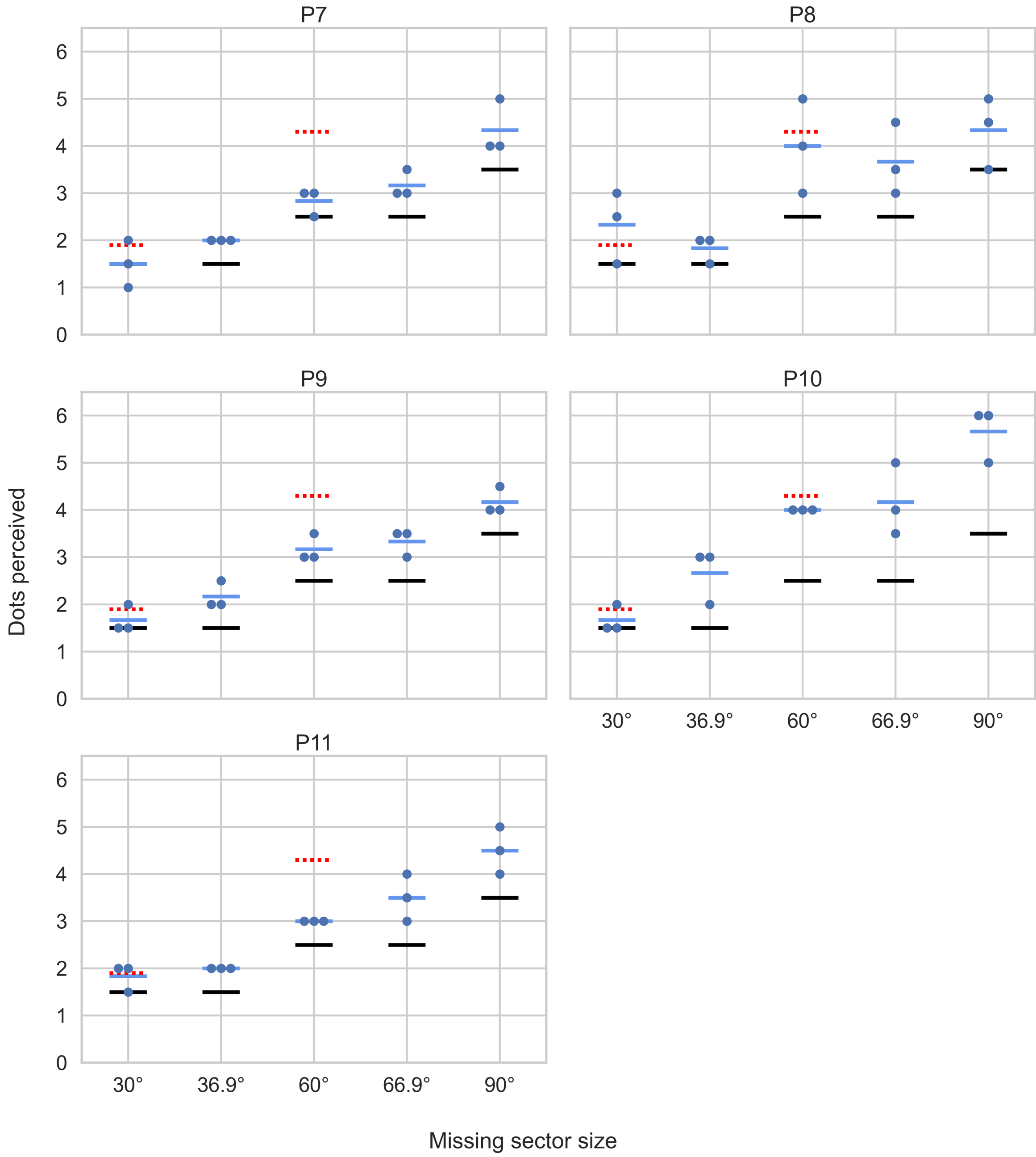


Figure 17: Participants 7-11 answer plots: the plots represent the answers given by each participant (P). The x-axis represents the size of the missing sector of the occluder. The y-axis shows the number of perceived dots by the participants. Each blue dot represents one answer by a participant for one trial. The black line indicates the amount of actual visible dots. The blue line shows the average of perceived dots by the participant. The red line indicates the results by Scherzer and Ekroll (2015) for the occluders with the 30° and the 60° occluder.

C Handout for the participants

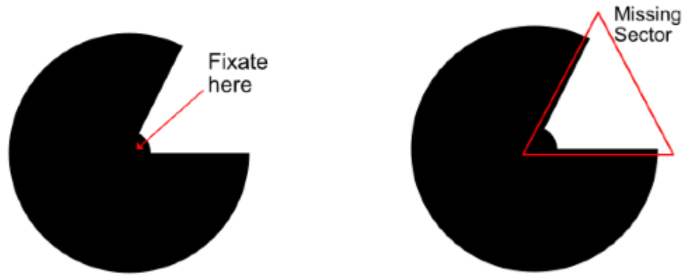
1 Participant Handout

1.1 Your Task

Count the amount of white dots you can see at once within the missing sector at every moment

1.2 Occluders

The occluder will be changed after every trial. The occluders have a missing sector. The missing sector varies. Focus on the center of the occluder.



(a) fixate your view on the center of the occluder while it is spinning

(b) Count the amount of white dots you can see within the missing sector

1.3 Keyboard

1. Enter the number of dots you can see
2. You can enter a range of +1, by pressing the number followed by a "+"
3. Press the green key twice to confirm your input
4. Use the red key to reset your input

NOTE: You cannot change your input after the confirmation

2 General information

2.1 Visual aid

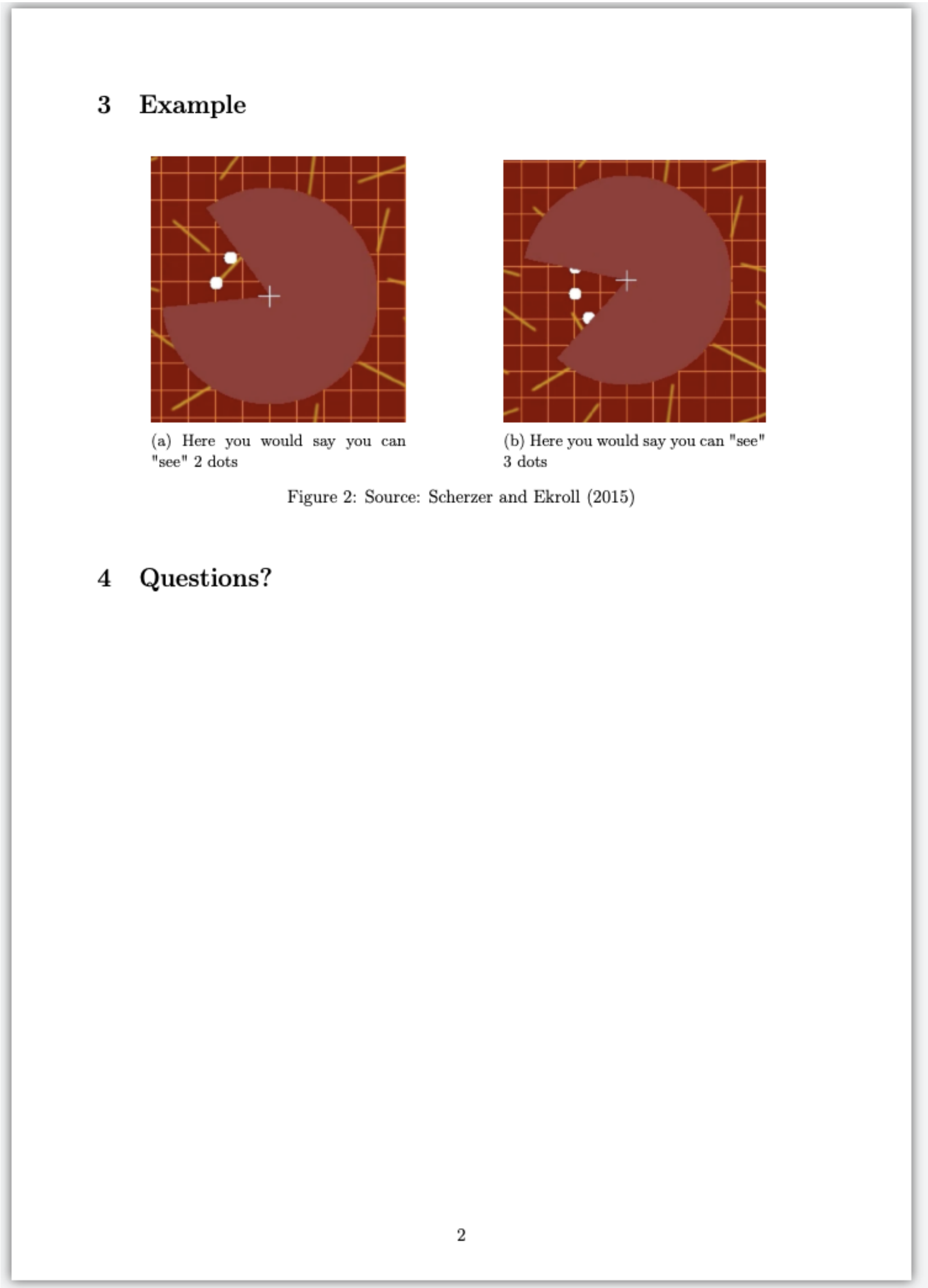
If you need a visual aid to see clearly within 1 meter, you must wear the required visual aid to participate in this experiment.

2.2 Possible risks

No risks are expected within the scope of the study.

1

Figure 18: Handout first page: First page of the handout that all participants were instructed with.



3 Example

(a) Here you would say you can "see" 2 dots

(b) Here you would say you can "see" 3 dots

Figure 2: Source: Scherzer and Ekroll (2015)

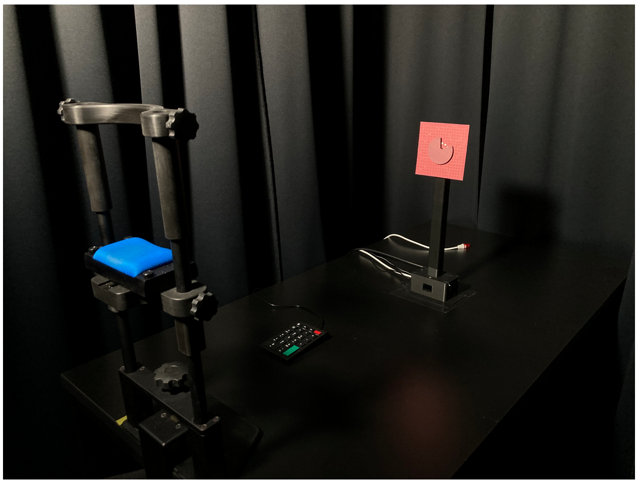
4 Questions?

2

Figure 19: Handout second page: Second page of the handout that all participants were instructed with.

D Setup pictures

(a)



(b)

Figure 20: Experiment Setup: Figure (a) shows the prototype through the head-rest. Figure (b) shows the experiment setup from the side.

(a)

(b)

Figure 21: Experiment setup 2: Figure (a) shows a participant sitting on the experiment setup with the chin placed on the headrest and looking towards the apparatus. Figure (b) shows the lamp used for the experiment setup, slightly angled down towards the apparatus.

E Light measurement

In the experiment setup, the light source stood on a tripod behind the participants (Figure 9). Because each participant wore individual clothing and had different hairstyle, the amount of light received by the light sensor varied between the participants (147.0 - 192.9 lux).

The light sensor was placed in the lid of the bottom compartment of the apparatus (Figure 4). Therefore the individual clothing, the hairstyle and hight of the participants influenced the amount of light that reached the light sensor. Also the manual removing of the visual block between the participant and the prototype was inconsistent and influenced the amount of light captured.

Figure 22 demonstrates the light captured by the participants for each participant during each trial.

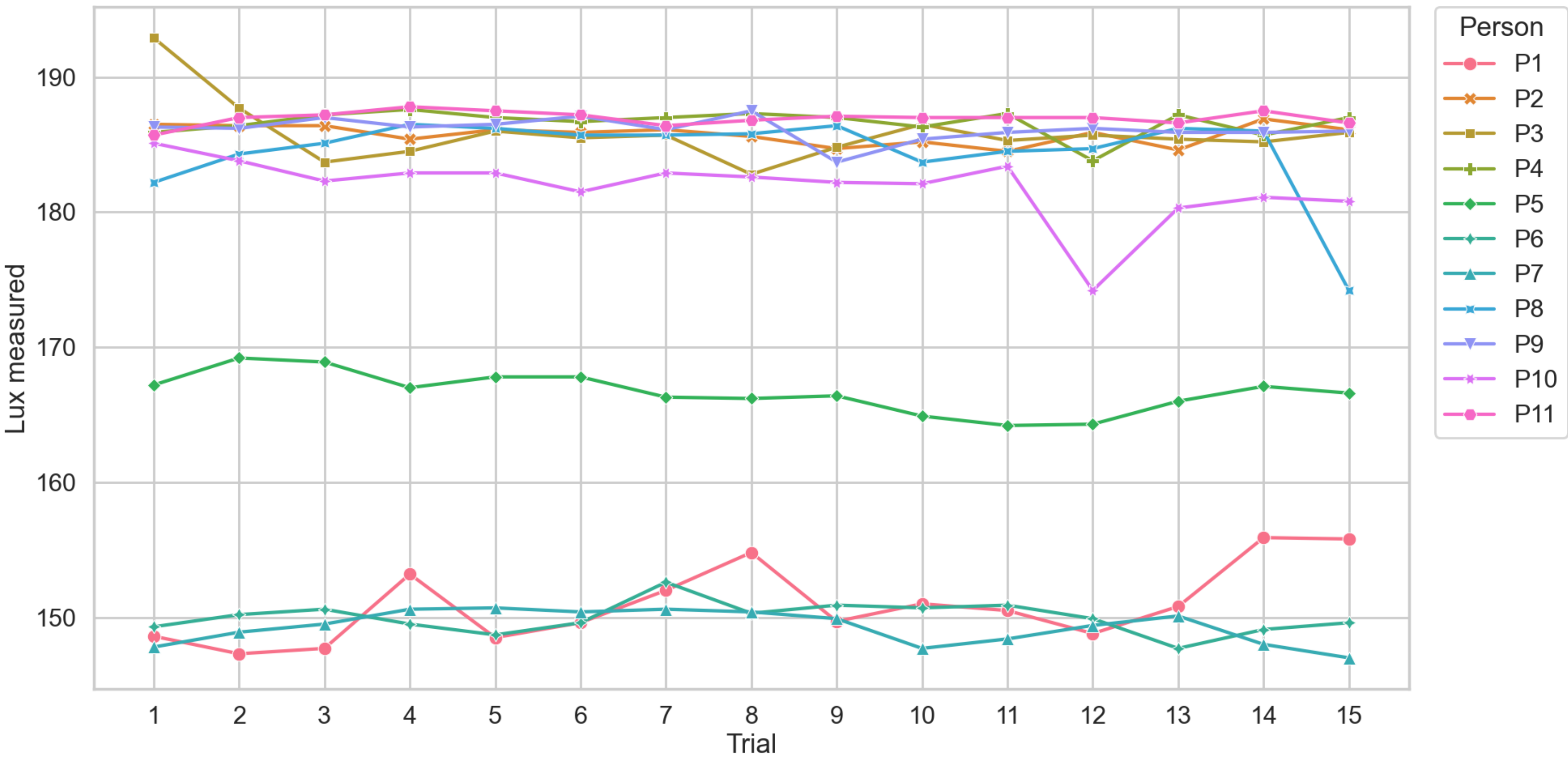


Figure 22: Light sensor data: measured brightness per participant in every trial.

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